

# Using EcosimPro for Thermal and Thermo-Hydraulic Analysis in ESA

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## ABSTRACT

EcosimPro is a multi-disciplinary simulation tool with a powerful object-oriented simulation language, state of the art solvers and a user-friendly environment with the look and feel of Microsoft® Visual Studio. It is the recommended ESA simulation tool for ECLS and has been used successfully for the European activities of the International Space Station program. Given its potential to address any kind of simulation, EcosimPro is increasingly being used at ESA and in Industry to carry out thermal and thermo-hydraulic simulations. This paper describes how EcosimPro can be used in this context and provides recent application examples.

## 1. INTRODUCTION

EcosimPro (formally Ecosim) is a generic simulation tool developed within an ESA supported activity since 1989. The development was driven initially by the increasing requirements to perform multi-disciplinary ECLS simulations. The ECLS library was first released in 1990 and since then, has been continuously maintained, upgraded and verified. EcosimPro is nowadays a state of the art tool to address ECLS analysis [1].

In 1997, the major decision was taken to redesign and to migrate the tool from Unix, the original supported platform environment, to PC. A new user interface has been built with the look and feel of Microsoft® Visual Studio. This provides a user-friendly framework to build, archive, maintain and run simulations. A schematic editor has been built on top of Smartsketch® of Intergraph. This facilitates model building with pre-defined building blocks. Finally, the language, built on top of C++, has been significantly upgraded to support Object-Oriented modeling functionality.

The user base welcomed the new version released at the end of 1999. As a result, new users have come to use the tool for several applications other than ECLS. In particular, EcosimPro is increasingly being used or evaluated in Europe [2] and in the USA to carry out thermal and thermo-hydraulic applications.

When compared to specific thermal analysis tools, EcosimPro provides additional functionality and flexibility to represent systems with thermal nodes but also with fluid loops, control laws etc. Examples of applications where EcosimPro can bring significant added value are multi-disciplinary medium size system analysis, design and verification of thermo-hydraulic components and identification of control laws. However, EcosimPro is not designed to handle large-scale models, such as the ones which are typically developed for the thermal control simulation of a spacecraft in phases B and C. Traditional thermal tools such as ESATAN and SINDA are more appropriate to address these needs.

Section 2 describes the advantages and disadvantages of the EcosimPro software for the thermal end-user. Recent applications are briefly described in section 3 and in section 4.

## 2. ECOSIMPRO FEATURES AND CAPABILITIES FOR THERMAL AND THERMO-HYDRAULIC MODELING

Papers [3] and [4] provide useful references for the reader. Only the main points of interest for the thermal engineer are included in the following description.

## 2.1 ECOSIMPRO LANGUAGE AND COMPONENTS

### 2.1.1 EcosimPro language (EL) - An Object-Oriented Modeling (OOM) simulation language

EL is a comprehensive simulation language which enables the user to use object-oriented modeling without having to have programming experience in this field. EL is a layer on top of C++ and the software automatically generates C++ code which is hidden for the user. The mechanism is the same as for older tools such as ESATAN or SINDA which are built on top of Fortran.

Nearly all the powerful capabilities of a true Object-Oriented Language (inheritance, aggregation) are accessible but with a reasonable level of complexity to define, execute and post-process an analysis.

EL supports also symbolic equations and "non causality". As a simple example, let us consider the definition of a thermal diffusive node in EcosimPro. This is done by writing:

$$T' = q / MC \quad (\text{Eq. 1})$$

$T'$  (°C/s) is the derivative of the temperature with respect to time.  $q$  (W) is the incoming heat flux in the node.  $MC$  (J/kg.K) is the node thermal capacitance.

By non causality we understand that Eq. 1 defines a relationship between the three variables and that EcosimPro treats Eq. 1 exactly in the same way than if the user would have written  $MC = q / T'$  or  $q = MC.T'$ . In other words, the user does not need to make some assumptions on what are the known and the unknown variables of the simulation. What is known (boundaries) and what is unknown is specified when an analysis case is defined and run. This clear separation between a model (component in EcosimPro terminology) and the analysis cases (experiments in the EcosimPro terminology) that are executed on this model facilitates the reusability, verification and configuration control of the model.

### Illustrations

1. The detailed model of an equipment – EQUIP - is created. a/ Verification: An analysis case Unit\_testing is defined and executed, specifying the unknown interfaces as boundaries (sink temperatures and interface fluxes). b/ Integration: Once the verification has been carried out, the model EQUIP can be implemented as part of a system-level model without being modified.
2. The thermal model of a system – SYSTEM - is created. a/ Heater sizing: An analysis case is defined specifying that some of the thermal nodes act as boundaries and sink sources. b/ Transient

verification: An analysis case is defined using the model SYSTEM without being modified.

### 2.1.2. Building modeling blocks - Components

The basic modeling block in EcosimPro is the component. This may contain in particular:

- PORTS, for connection with other components. They can be of several types e.g. thermal, fluid, electrical. They can be created and customized by the user.
- DATA, which are visible.
- Variables, which are private.
- Continuous equations and/or discrete events.

The EcosimPro component is like a (sub)model in ESATAN. Examples of components are nodes, conductors, heaters, pipes, pumps, condensers, heat exchangers, controllers, cooling systems, equipment, the ISS Columbus.

When compared to ESATAN and other thermal analysis tools, EcosimPro provides the additional capabilities:

- Interfaces are clearly defined using PORTS and public data. Nodes (thermal or others) are only used internally in a component. As far as the interface remains the same, the component can be upgraded by the user (refined local mesh for example) without impact on the other components.
- Dynamic allocation is supported hence the user can specify dynamically the number of nodes to be handled within a component. The only limitation is that this can not be changed at run-time level.
- Some variables are private hence their integrity is guaranteed.
- Because EL is an Object-Oriented language, components can be derived from existing components (inheritance). For example, a PID can be derived from a PI by specifying additional functionality. Each change to the component PI will be automatically propagated to the component PID, see figure 1 for illustration.

```
COMPONENT Cntrl_pid IS_A Cntrl_pi

DATA
  REAL Td = 0.1           "Rate or derivative time (s)"
  REAL alpha = 0.1 RANGE 0., 1. "Derivative filter parameter"

DECLS
  REAL yf           "Filtered variable"

CONTINUOUS

  yf' = (y - yf) / (alpha * Td)

<:V> v = k * (beta * r - y - Td * yf) + vi

END COMPONENT
```

Figure 1 – Using EL to define a PID component from a PI component

Figure 2 shows how this approach is followed to define the hierarchical dependence of hydraulic components.

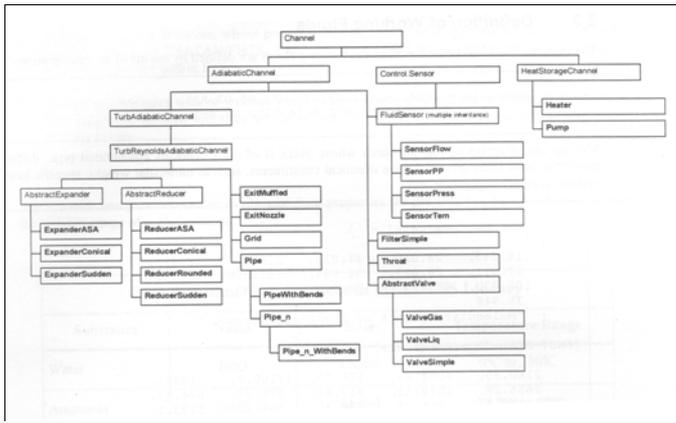


Figure 2 – Dependency tree for a sub-set of hydraulic components

A driving requirement to design and assemble (aggregate) components in Object-Oriented tools is that a component interface should be kept to a minimum. This facilitates the reusability and the verification of the component. Figure 3 illustrates this point. Pipe is a relatively simple component computing the fluid for an adiabatic pipe.

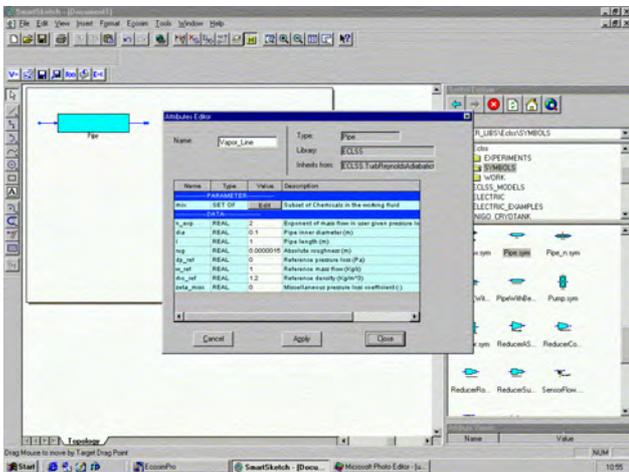


Figure 3 – Pipe component in EcosimPro / Smartsketch

Interfaces are defined clearly and are likely to be easy to maintain. Any adiabatic pipe will require an inlet fluid port and an outlet fluid port for connection to other components. This does not mean that the internal description of the component may not evolve. For instance, the pressure drop could be computed with a new established correlation. Also, when defining a specific pipe, the user can allocate a number of fluid

nodes and change them later on without affecting the interface.

It is relatively straightforward to design components using the Object-Oriented approach for use with physical objects and this is therefore well adapted to encapsulate local physical phenomena such as conduction and advection in fluids. The approach is however less intuitive when radiation is predominant i.e. with space applications. Radiation is not attached to a physical object but is an interaction between physical objects. In practice, the thermal engineer may need to compute a (very) large number of radiative conductors and to use these values as input data to compute the temperatures within EcosimPro. Encapsulating these radiative conductors in components does not present any particular difficulties. On the other hand this may require a multiplication of interfaces at the component level (one part of the system can radiate with several other parts of the system). As a result this can in practice limit the reuse of the components involved. As with any tool there is little that EcosimPro can do to address this limitation.

### 2.1.3. Component management - System / User libraries

Figure 4 shows a view of the EcosimPro user interface. Standard libraries are provided with the tool, ECLS, THERMAL etc. In this example, the system administrator has locked (read only) the standard libraries to guarantee their integrity and the user has defined a THERMAL\_CUSTOMISED library to implement his own thermal components. The example shows a diffusive node with additional attributes to compute in real-time the min and max values during a transient. Other attributes can be, for example, specified temperatures, a Boolean to indicate whether min/max specifications are fulfilled, a Boolean to track whether a cyclic behavior has been reached in orbit etc. This functionality is an asset when compared to specific thermal tools. EcosimPro is a software designed to use, maintain, extend and customize libraries to fulfill specific needs.

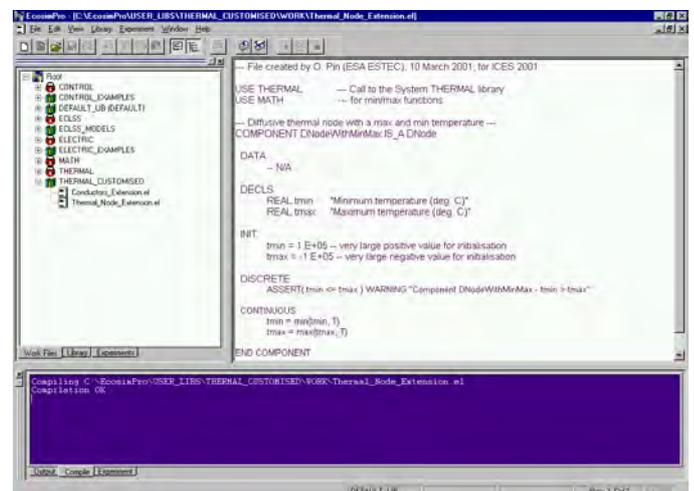


Figure 4 – The EcosimPro environment and a simple example of user-customized component

In the last years, the THERMAL library (see figure 5) has mainly been used as a service library for ECLS analyses and thus contains a limited set of components. The library will be upgraded in the future to address user requests.

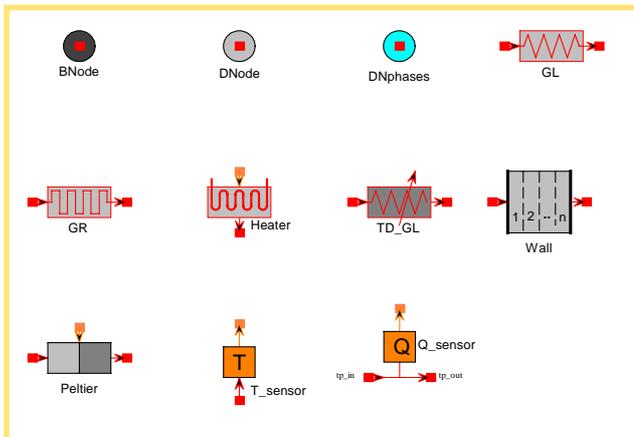


Figure 5 – Components of the EcosimPro THERMAL library

A useful feature of EcosimPro is that it provides an automatic dependency tree (actually a hidden makefile) to ensure that any change to a component is automatically handled by the software. The consistency of components is also checked and if necessary recompiled including dependencies when an analysis case is run. This process is not always supported in thermal analysis tools.

## 2.2. ECOSIMPRO KERNEL

EcosimPro can be applied to any problem that can be formulated with differential and algebraic equations.

The two user requirements to support symbolic equations and non-causality in the EcosimPro language level are translated, at the kernel level, by the need to provide a series of built-in mathematical algorithms to transform continuous equations and discrete events. The transformations are symbolic (find variables, symbolic derivation) and numeric (simplification of coefficients). The software uses the graph theory to analyze equation models and to detect inconsistencies and redundancies.

The non-causality of the language can be a drawback. Potential unknowns of the problem can become high as not only the temperatures are pre-supposed to be the unknowns that can be calculated. Rearranging the system of equations can thus be CPU time consuming. This is one of the current limitations of the tool when it is used for models containing a very large number of

equations, such as the large radiative and conductive networks to be handled for an overall spacecraft system-level analysis.

Reporting capabilities are available for the user to check the effects of the different transformations of the equations and to “debug” the model. A mathematical model view is automatically generated for each run and provides statistics to the analyst e.g. to which extent a sparse solver is of interest, conditioning of matrices.

Simulations can be run as batch processes or using the EcosimPro monitor to plot results during the run.

## 2.3. POST-PROCESSING

EcosimPro stores all results in a binary database and post-processing capabilities are provided with the EcosimPro Monitor. The user can also specify whether some results have to be formatted as an input file for Microsoft® Excel.

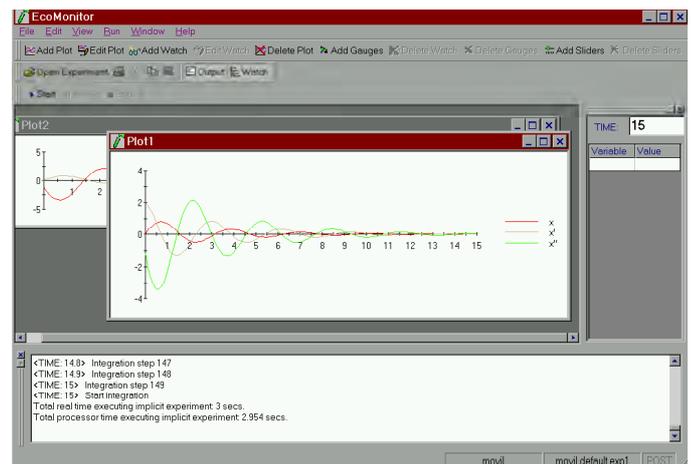


Figure 6 – View of the EcosimPro Monitor

As EcosimPro is a generic tool, there is no specific built-in functionality to compute heat flows, average temperatures of groups of nodes, sink temperatures etc. The feasibility of implementing an open interface to connect the tool with thermal analysis post-processing utilities will be assessed shortly.

## 3. EXAMPLE OF THERMAL MODELLING - PTDCU/LSS

This application was described in a previous paper and details are not repeated here [5].

The objective is to compute the temperatures of the PlaTanium resistor Multiplexer Board (PTMB) integrated in the Platinum Data Collection Unit (PTDCU) equipment, part of the Temperature Data Acquisition System (TEMPDAS) located in the ESTEC Large Space Simulator (LSS). The purpose of the analysis is to assess the maximum level of temperature in the PTDCU for a worst HOT case. Reference data from other models are available [5].

The PTDCU equipment is composed of five PTMB and two Power Supplies (PS). They are inserted via the front panel and are thermally and mechanically fixed to the side walls by wedge-lock clamps. Heat can only be evacuated through the side walls. The PTDCU operates under vacuum conditions in the LSS where the shroud temperature range is 80°C for a HOT case. The PTDCU external areas are partially covered by MLI. The PTDCU is fixed on a spin-box mounting plate where the temperature is 60°C for HOT conditions. Heat rejection is based on the conductive contact with the baseplate. The thermal contact is realized with ChoTherm and bolts on each foot.

Dissipative components are mounted on each PTMB. In nominal operational mode the internal dissipation per PTMB is 6.2W. Considering that the 2 power supplies dissipate 14W together, this means that the internal dissipation in the equipment is 45W.

In order to assess the PTMB worst HOT case, the uppermost PTMB single thermal node (node 34) is replaced by a detailed model (135 + 2 nodes).

The approach followed is described on figures 7 and 8.

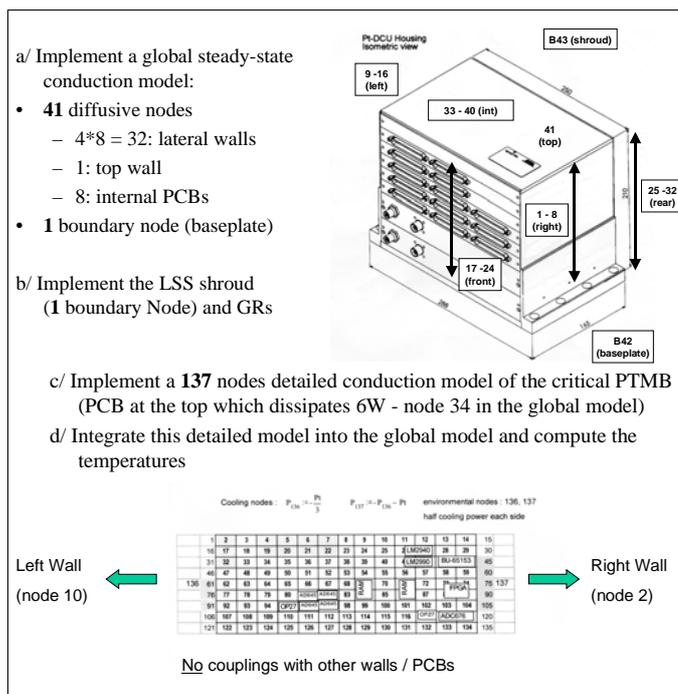


Figure 7 – PTDCU thermal modeling steps

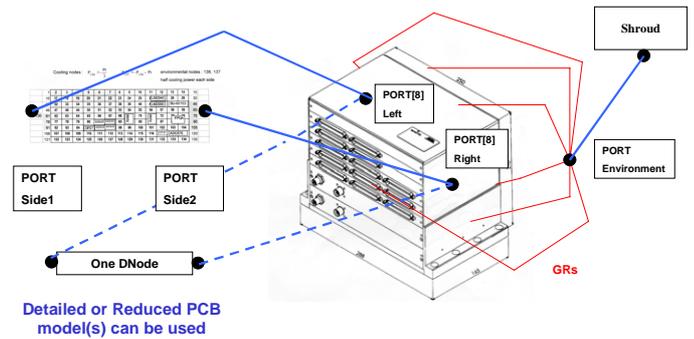


Figure 8 – PTDCU modeling approach with EcosimPro

The temperatures computed are very close to those obtained with other tools. A significant temperature gradient (between +72.4°C and +88.2°C) is obtained in the PTMB. The predicted maximum temperature is +88.2°C.

This application shows a case when radiation is easy to encapsulate within a component with limited interface (an environment PORT has been used and all radiative links are connected to this PORT). Also, at the PTMB level, the fact that interfaces are only conductive make the component construction with EcosimPro very intuitive. It would be easy to upgrade the detailed model, implement local changes. Computing a COLD case, requiring to use a detailed model of the lower PTMB would be straightforward.

It can be concluded that EcosimPro is a well suited, fast turn-around and intuitive tool for this type of small-size thermal analysis.

#### 4. EXAMPLE OF THERMO-HYDRAULIC MODELING - RFR

EcosimPro was used as a shadow engineering tool to simulate the operation of the Refrigerator Freezer Rack's (RFR) of the International Space Station [6]. Thermal, thermo-hydraulic and control components were considered for the simulation. Results were compared with the thermal PC ESATAN model developed by Industry [7].

The RFR's are the basic equipment for the transfer of crew food, experiment material and medicine from ground to the ISS as well as for the retrieval of science samples/specimen, reagents, chemicals and waste material from the ISS back to ground.

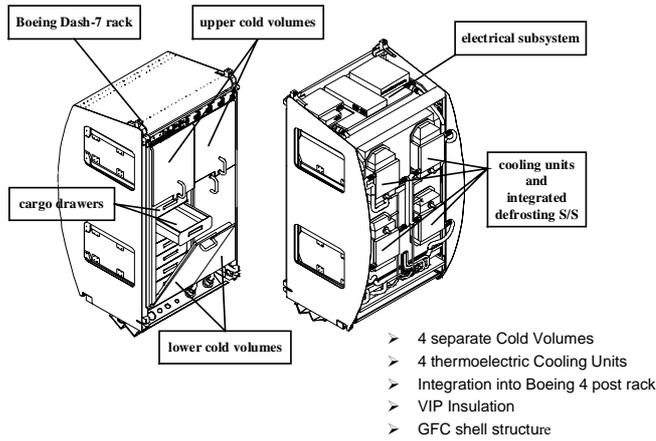


Figure 9 – RFR description – from Ref. [7]

The phenomena represented by the model are:

- Heat Transfer between the CV (cold volume), and between the CV and the environment
- Thermal Capacity of insulation walls, external layer, drawers, cargo, and air
- Volume air flow from the balance between the pressure rise in the fan, and the pressure drops
- Heat transfer from the cabin air by convection
- Detailed behavior of the HX with the Peltier Units
- Defrosting heating cycle
- Fluid flow through the wick and capillary channels in a simplified way
- Behavior of the Peltier heat exchanger from performance curves

It is not the objective of this paper to present details of the model and results but rather to illustrate how EcosimPro facilitates the maintenance and exploitation of the model. A top-down architecture is used, and changes of data values at the higher levels of the hierarchy are automatically propagated downwards. This feature of the model facilitates its maintenance and its exploitation.

Figure 10 shows an example of component specifically developed for this application. The component represents half rack assuming that the RFR is operated symmetrically to minimize heat leaks into the cold volumes.

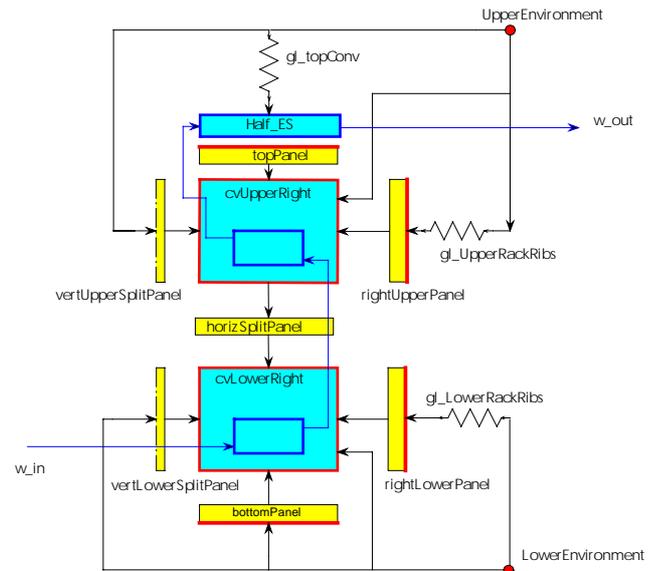


Figure 10 - Topology of the RFR component HalfRackRight

Figure 11 shows the topology of the Cold Volume component CV. This component represents a Cold Volume including:

- Inner layers of the lateral walls of the cold volume
- Air Gap circuit
- Drawers and Cargo
- Cooling Unit
- Cold volume controller
- Door
- Back insulation panel

In particular, the CV component does not include the insulation layer, and the outer layers of the top, bottom, right and left panels to enable the modular construction of the component representing a Half Rack.

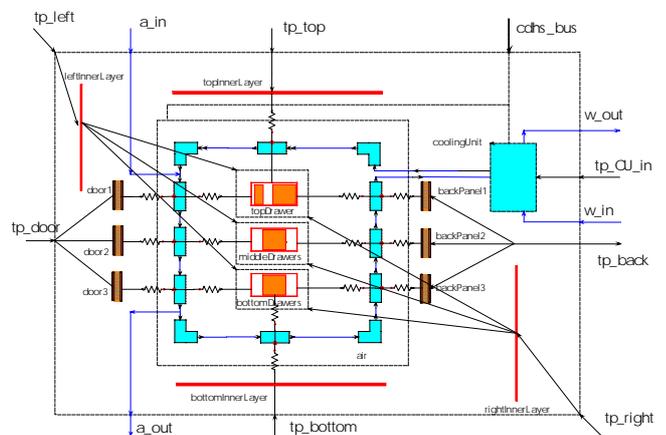


Figure 11 - Topology of the component CV

Typically the RFR model contains 2362 independent variables, 2354 equations (179 DAE and 2175 Algebraic explicit equations), and requires 8 boundary conditions.

Several steady state and transient analyses have been carried out within the frame of the activity. A detailed description of the simulation and results obtained will be given in a separate paper.

EcosimPro has proven to be well suited for this kind of analysis and its use will be promoted by the Agency for similar applications.

## CONCLUSION

EcosimPro is an appropriate simulation tool for the detailed modeling of thermal and thermo-hydraulic (sub)systems. There is potential for various applications such as design of thermal protection subsystems, mechanical coolers or two-phase capillary fluid loops.

Future activities will also concentrate on addressing the current lack of interface of the tool with ESA supported and well-established thermal analysis tools such as ESATAN, FHTS and ESARAD.

## ACKNOWLEDGMENTS

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